

Dis, inc. Track record

Seven structures incorporating seismic isolators have been subjected to six different earthquakes in the United States, New Zealand and Japan. Each of these events have produced acceleration levels at the base of the structures in excess of 0.20g. These structures rode out the earthquakes without structural damage or disruption to contents or services.

One of the most recent examples involved the USC University Hospital, isolated by DIS technology in 1991. In the 1994 Northridge earthquake, the hospital suffered no damage and remained operational while an adjacent hospital complex without isolators sustained \$389 million in damages. Two wings of that unprotected hospital remain permanently closed.

On April 25, 1992, the largest peak ground acceleration ever recorded in California (2g) occurred at Cape Mendocino, 2.5 miles from the epicenter of a surface wave magnitude (Ms) 7.0 earthquake. Located about 14 miles from the epicenter is the Eel River Bridge, which had been retrofitted in 1987 with lead-rubber seismic isolators. The bridge suffered no damage.

The Mark II Detector at the Stanford Linear Accelerator Center was 32 miles from the epicenter of the 1989 Richter magnitude 7.1 Loma Prieta earthquake. A peak ground acceleration of 0.29g was recorded on nearby Stanford University campus. The Detector was estimated to move 4 inches and there was no damage.

Excerpted from <http://www.dis-inc.com>

Seismic Isolation- An Attractive Earthquake Insurance Policy

The Moment Magnitude (Mw) 6.7 Northridge earthquake occurred at 4:31 a.m., the morning of January 17, 1994, on a national holiday when most Californians were at home asleep. Fifty-seven persons lost their lives, nearly 9,000 were injured, and damage was in excess of \$20 billion. In many respects we were fortunate. The earthquake could have occurred during normal business hours, with freeways loaded to capacity, crowded shopping centers, people at work, and children in school. We cannot afford to rely on good fortune to minimize earthquake losses.

The Northridge earthquake demonstrated again that, while California's current building codes and practices are generally adequate to protect life safety, they fall far short of what is needed to protect Californians from the economic disaster that a major earthquake would cause.

In a few seconds on January 17, 1994, insurance companies sustained an estimated \$10 billion in losses.

Big numbers alone don't faze the insurance actuaries. What really shook the industry was comparing that loss with the \$3.4 billion in California earthquake insurance premiums collected in the previous 25 years, said Bill Pope, executive vice president of insurance for the real estate brokerage and insurance firm John Burnham & Company.

The realization that years of reserves could disappear almost instantly prompted an exodus from the stand-alone earthquake insurance field, said William Haberger, owner of B.H. Gold Insurance Agency.

“There’s no market,” he said. “There’s no company willing to write it.”

This doesn’t mean earthquake insurance is impossible to get, say Haberger and other industry executives.

Homeowners are able to use what amounts to an assigned-risk policy governed by the state if no private insurers step forward. Commercial property owners can include earthquake insurance in a comprehensive policy. But these alternatives mean more work by policyholders in tracking policies down and often higher costs than previously offered.

	Isolated Base		Fixed Base	
	X	Y	X	Y
Ground (Below Isolators)	0.30g	0.26g	0.27g	0.26g
1st Floor (Above Isolators)	0.11g	0.06g	--	--
Top Floor (6th Isolated, 5th Fixed Base)	0.10g	0.07g	0.97g	0.67g
Amplification Ratio (Roof/Ground)	0.033	0.28	3.6	2.6
Amplification Ratio - Roof (Fixed Base/Isoalted)	--	--	9.7	9.6

Deductibles that were 10% prior to Northridge are now rising to the 15—20% range. Insurance premiums are also rising when they are available.

Aside from being a tragedy in its own right, the Northridge quake “brought into focus the magnitude of the exposure that is faced” in insuring California real estate, Pope said.

About 25 percent of all state homeowners and 10% of businesses historically have opted to purchase earthquake insurance, Pope said. “In today’s environment, there is no way to have a sufficient spread of risk, which is one of the principles of insurance” Pope said. “We cannot be sure if another 25 years will go by before we get another earthquake of this magnitude.”

Seismic isolation is an attractive earthquake damage mitigation measure and the additional costs to incorporate it is the equivalent to the cost of 3 to 5 years of the insurance premium. It can be considered as a substitute or supplement, but in any case it is a preventative approach to the problem. In 1989, Sherwin Small, the Executive Vice President of National Medical Enterprises (the owners of the USC University Hospital), said that the additional 2% first cost was a cheap insurance policy against a big earthquake. He was most prophetic—the USC hospital suffered no damage in the 1994 Northridge earthquake. By contrast, the adjacent L.A. County USC Medical Center suffered \$389 million in damage with two wings closed.

Kobe Earthquake:

Effectiveness of Seismic Isolation Proven Again

The images of damage coming out of Japan have been a shock to both the public and the engineering community. Thousands of structures of all types have either collapsed or have been badly damaged. The impact on business has, and will continue to be, devastating. Despite the trauma, however, there is good news.

Exactly one year after the Northridge earthquake, seismic isolation proves, once again, to be the best insurance against loss of life, structural damage, content damage and business disruption.

One of the world's largest seismically isolated structures, approximately 20 miles northwest of Kobe, suffered NO DAMAGE at all and performed exactly as planned. The West Japan Postal Savings Computer Center, of the Ministry of Post and Telecommunications, is a 6-story, 500,000 sq.ft. reinforced concrete building that is isolated on a system which includes lead-rubber isolators. The building was fully instrumented and recorded the following peak accelerations. A comparison with a fixed base building nearby shows that the peak floor accelerations at the roof were reduced by a factor of approximately 9. It is this reduction in floor acceleration that provides for the safety of not only the structure, but more importantly, the contents of the building.

Los Angeles Earthquake:

On January 17, 1994, in Northridge, California, a Moment Magnitude (Mw) 6.7 trembler significantly damaged 31 Los Angeles area hospitals, forcing 9 to fully or partially evacuate. Content damage ran into the billions of dollars. USC University Hospital, however — the world's first "seismically isolated" hospital — gently rode out the quake with no damage at all. The L.A. County USC Medical Center, one kilometer away, suffered \$389 million in damage, with two wings permanently closed.

In 1990, USC University Hospital's owners, National Medical Enterprises, Inc. (NME), determined when they built their seismically isolated hospital that they would invest in the extra construction cost — about 2% additional — in hopes of saving a fortune in repair costs in the event of an earthquake. The additional 2% initial cost was viewed as cheap insurance. They were most prophetic: Their investment, and that of the Ministry of Post and Telecommunications in Japan, paid off handsomely.

On April 25, 1992, a Surface Wave Magnitude (Ms) 7.0 earthquake occurred in Petrolia (Northern California) and produced the largest peak acceleration ever recorded: 2g. The Eel River Bridge, located about 16 miles from the epicenter, had been retrofitted in 1988 with lead-rubber seismic isolation bearings on its two 300-ft. through-truss spans. Although the Eel River Bridge was not instrumented, the instrumentation at the nearby Painter Street Overcrossing recorded peak ground accelerations of 0.55g and 0.39g in the longitudinal and transverse directions, respectively. The isolated truss spans moved 8 inches longitudinally and 4 inches transversely, with no damage to the trusses or supporting spans.

Seismic isolation of bridges is increasing on a nation-wide basis, with a total of 76 in 21 states, to date.

Seismic isolation provides two significant design features for a bridge. First, it can reduce the seismic forces by a factor ranging from 3 to 8. Second, it can control the distribution of these reduced lateral forces among the substructures and foundations to further enhance the overall economy and effectiveness of new and retrofit designs.

For example, in new construction, seismic isolation has produced overall net cost savings of 4% for a 6-span bridge in New Hampshire ($A = 0.15g$), 12% for an 8-span bridge in Oregon ($A = 0.29g$) and 12% for a 4-span Caltrans (California DOT) bridge ($A = 0.60g$) — mainly due to cost savings in foundations. Consequently, the earthquake safety of a bridge can be improved significantly, at a similar or less cost than that of conventional construction.

Base Isolation: Origins and Development

James M. Kelly

Professor Emeritus Civil and Environmental Engineering

University of California, Berkeley

In recent years base isolation has become an increasingly applied structural design technique for buildings and bridges in highly seismic areas. Many types of structures have been built using this approach, and many others are in the design phase or under construction. Most of the completed buildings and those under construction use rubber isolation bearings in some way in the isolation system.

The ideas behind the concept of base isolation are quite simple. There are two basic types of isolation systems. The system that has been adopted most widely in recent years is typified by the use of elastomeric bearings, the elastomer made of either natural rubber or neoprene. In this approach, the building or structure is decoupled from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation. This layer gives the structure a fundamental frequency that is much lower than its fixed-base frequency and also much lower than the predominant frequencies of the ground motion. The first dynamic mode of the isolated structure involves deformation only in the isolation system, the structure above being to all intents and purposes rigid. The higher modes that will produce deformation in the structure are orthogonal to the first mode and consequently also to the ground motion. These higher modes do not participate in the motion, so that if there is high energy in the ground motion at these higher frequencies, this energy cannot be transmitted into the structure. The isolation system does not absorb the earthquake energy, but rather deflects it through the dynamics of the system. This type of isolation works when the system is linear and even when undamped; however, some damping is beneficial to suppress any possible resonance at the isolation frequency.

The second basic type of isolation system is typified by the sliding system. This works by limiting the transfer of shear across the isolation interface. Many sliding systems have been proposed and some have been used. In China there are at least three buildings on sliding systems that use a specially selected sand at the sliding interface. A type of isolation containing a lead-bronze plate sliding on stainless steel with an elastomeric bearing has been used for a nuclear power plant in South Africa. The friction-pendulum system is a sliding system using a special interfacial material sliding on stainless steel and has been used for several projects in the United States, both new and retrofit construction.

Research at EERC

Research on the development of natural rubber bearings for isolating buildings from earthquakes began in 1976 at the Earthquake Engineering Research Center (EERC) (now PEER, the Pacific Engineering Research Center) of the University of California at Berkeley. The initial research program was a joint effort by EERC and the Malaysian Rubber Producers Research Association (MRPRA), U.K. The program was funded by MRPRA through a number of grants over several years, with later funding provided by the National Science Foundation and the Electric Power Research Institute. Professor James M. Kelly directed the research at EERC, which included considerable theoretical and experimental contributions by graduate students.

Although not an entirely new idea at the time—a few methods using rollers or sliders had been proposed—the concept of base isolation was considered to be very impractical by most of the structural engineering

profession. The research project began with a set of hand-made bearings of extremely low-modulus rubber used with a simple three-story, single-bay, 20-ton model. Shaking table tests showed that isolation bearings could bring about reductions in acceleration by factors of as much as ten when compared to those of conventional design and that, as predicted, the model would respond as a rigid body with all deformation concentrated in the isolation system. It was also clear that a certain degree of damping was needed in the system and that the scale of the model was too small to allow more practical rubber compounds to be used.

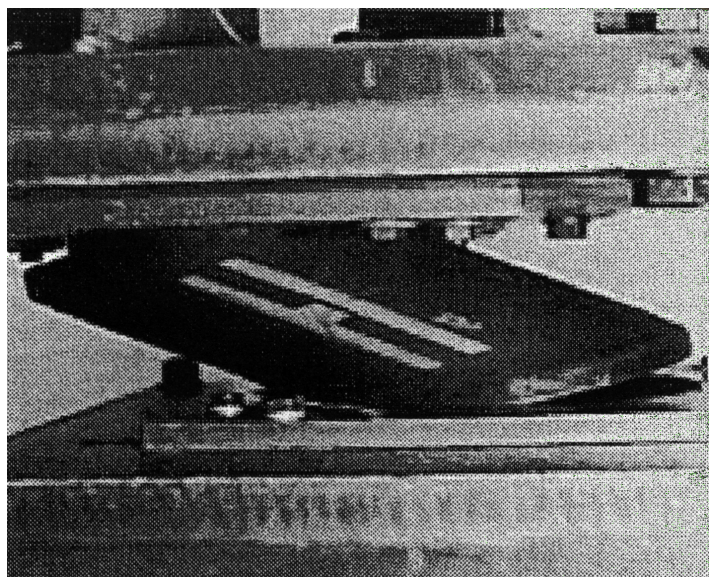
In 1978, a more convincing demonstration of the isolation concept was achieved with a more realistic five-story, three-bay model weighing 40 tons and by using damping-enhanced bearings made by commercial techniques. A strong interest throughout the EERC research program was in the influence of isolation on the response of equipment and contents in a structure, which tend to sustain more damage when conventional methods of seismic-resistant design are used and which, in many buildings, are much more costly than the structure itself. An extensive series of tests on the five-story frame demonstrated that isolation with rubber bearings could provide very substantial reductions in the accelerations experienced by internal equipment, exceeding the reductions experienced by the structure. However, the same tests showed that when additional elements (such as steel energy-absorbing devices, frictional systems, or lead plugs in the bearings) were added to the isolation system to increase damping, the reductions in acceleration to the equipment were not achieved because the added elements also induced responses in the higher modes of the structure, affecting the equipment. It became clear that the optimum method of increasing damping was to provide it in the rubber compound itself. This method was applied later in the compound developed by MRPRA and used in the first base-isolated building in the United States, described below.

Rubber bearings are relatively easy to manufacture, have no moving parts, are unaffected by time, and are very resistant to environmental degradation.

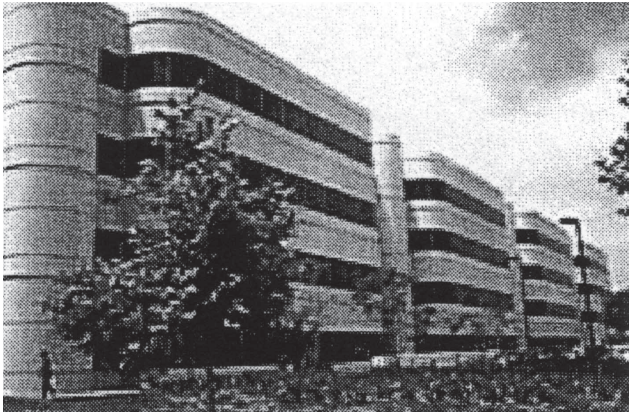
U.S. Applications

The bearings are made by vulcanization bonding sheets of rubber to thin steel reinforcing plates. Because the bearings are very stiff in the vertical direction and very flexible in the horizontal components of the ground movement while the vertical components are transmitted to the structure relatively unchanged. Although vertical accelerations do not affect most buildings, the bearings also isolate the building from unwanted high-frequency vertical vibrations produced by underground railways and local traffic. Rubber bearings are suitable for stiff buildings up to seven stories in height. For this type of buildings, uplift on the bearings will not occur and wind load will be unimportant.

The first base-isolated building in the United States is the Foothill Communities Law and Justice Center, a \$30 million legal services center in Rancho



*Test of bearing used in the Indonesian demonstration building.
Photo: L.D. Aiken*

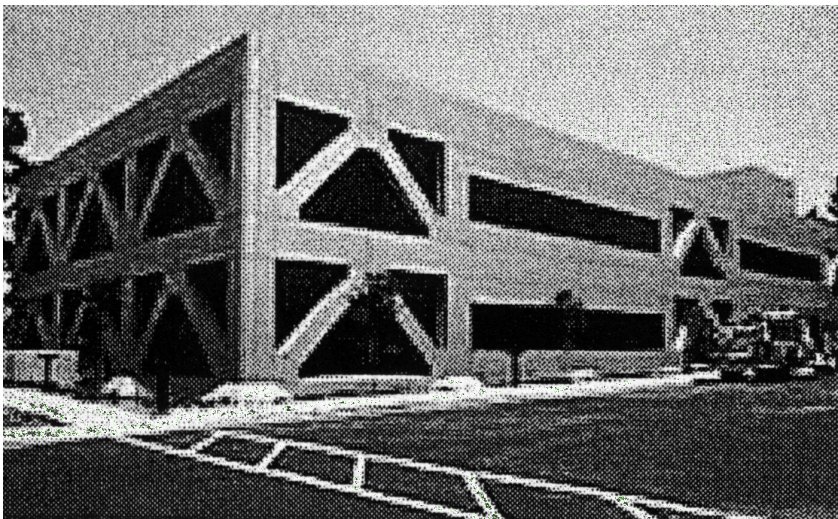


*Foothill Communities law and Justice Center.
Photo: L.D. Aiken*

Cucamonga San Bernardino County, about 97 km (60 miles) east of downtown Los Angeles. Completed in 1985, the building is four stories high with a full basement and sub-basement for the isolation system, which consists of 98 isolators of multilayered natural rubber bearings reinforced with steel plates. The superstructure of the building has a structural steel frame stiffened by braced frames in some bays.

The building is located 20 km (12 miles) from the San Andreas Fault: San Bernardino County, the first in the U.S. to have a thorough earthquake preparedness program, asked that the building be designed for a Richter magnitude 8.3 earthquake, the maximum credible earthquake for that site. The design selected for the isolation system, which accounted for possible torsion, incorporated a maximum horizontal displacement demand of 380 mm (15in.) in the isolators at the corners of the buildings. Tests of full-scale sample bearings verified this capacity.

The highly filled natural rubber from which the isolators are made, developed as part of the EERC research program, has mechanical properties that make it ideal for a base isolation system. The shear stiffness of this rubber is high for small strains but decreases by a factor of about four or five as the strain increases, reaching a minimum value at a shear strain of 50 percent. For strains greater than 100 percent, the stiffness begins to increase again, providing a fail-safe action under a very high load. The damping follows the same pattern but less dramatically, decreasing from an initial value of 20 percent to a minimum of 10 percent and then increasing again. The design of the system assumes minimum values of stiffness and damping and a linear response. The high initial stiffness is invoked only for wind load design and the large strain response only for fail-safe action.



*Fire Department Command and Control Facility
Photo: L.D. Aiken*

This high-damping rubber system was also adopted for the Fire Department Command and Control Facility (FCCF) of Los Angeles County, completed in 1990. (The same type of high-damping rubber bearing was also used for the Italian telephone company, S.I.P., Ancona, Italy, the first modern base-isolated building in Europe.) The FCCF building houses the computer systems for the emergency services of the county and is therefore required to remain functional after an extreme event. *Fire Department Command and Control Facility Photo: L.D. Aiken*

The decision to use base isolation for this project was reached by comparing conventional and isolation schemes designed to provide the same degree of protection. In most projects, the isolation design cost five percent more. Not only was the isolation design estimate six percent less in this case but is less for any building when equivalent levels of protection are

considered. Furthermore, these costs are first costs. Life-cycle costs are even more favorable. Also noteworthy is that the conventional code design requires only a minimal level of protection, that the structure not collapse; whereas isolation design provides a higher level of protection.

The University of Southern California Teaching Hospital in eastern Los Angeles is an eight-story concentrically braced steel frame supported on 68 lead rubber isolators and 81 elastomeric isolators. The building was instrumented by the California Strong Motion Instrumentation Program soon after its completion in 1991. The foundation system consists of spread footings and grade beams on rock. Because of functional requirements, both the building plan and elevation are highly irregular with numerous setbacks over the height. Two wings at either side of the building are connected through what is referred to as the “necked-down” portion of the building, and in the original fixed-base design the irregular configuration led to both coupling between the lateral and torsional vibration modes and very large shear force demands in the slender region between the two rings. (Even in the isolated design steel trusses are required to carry the shears in the necked-down region.) These were two of the main reasons that seismic isolation was eventually chosen for this structure.



*University of Southern California University Hospital.
Photo: P.W. Clark*

The University of South California (USC) Teaching hospital was 36 km (23 miles) from the epicenter of the M~6.8 1994 Northridge earthquake. The peak ground acceleration outside the building was 0.49g, and the accelerations inside the building were around 0.10 to 0.13g. In this earthquake the structure was effectively isolated from ground motions strong enough to cause significant damage to other buildings in the medical center. The records obtained from the USC hospital are particularly encouraging in that they represent the most severe test of an isolated building to date.

Nuclear Applications

Isolation used in conventional nuclear plants greatly simplifies the expensive and time-consuming design and qualification of the equipment, piping, and supports for seismic loading. In addition, when seismic design criteria are increased due to the discovery of nearby faults, for example, the plant need not be redesigned; upgrading the isolation system is sufficient.

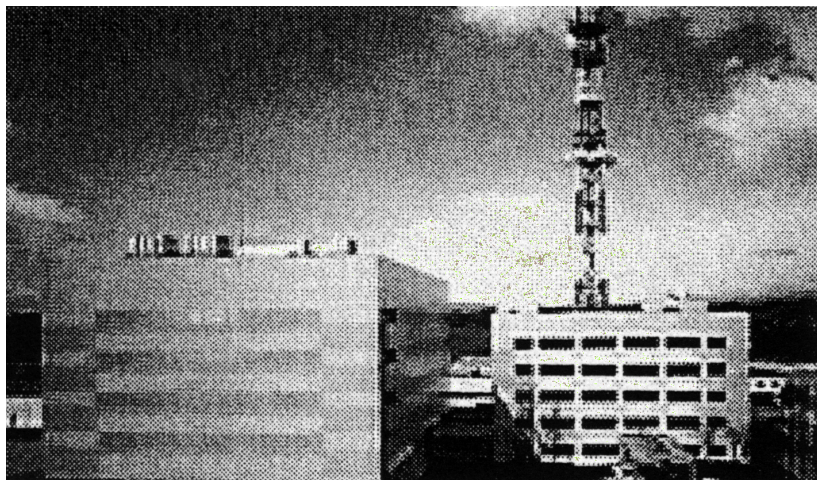
In an experimental program at EERC isolation bearings were designed, produced, and tested for two types of liquid metal reactor designs. The first, called PRISM, uses high-shape factor isolation bearings designed to provide horizontal isolation only. In the other design, SAFR, the reactor is supported on low-shape bearings that provide both horizontal and vertical isolation. The results of this test series extended the range of the isolator types with well-understood characteristics.

Base Isolation in Japan

After a slow start, base isolation research and development in Japan increased rapidly. The first large base-isolated building was completed in 1986. Although such buildings in Japan require special approval from the Ministry of Construction, as of June 30, 1998, 550 base-isolated buildings had been approved.

Base isolation has advanced rapidly in Japan for several reasons. The expenditure for research and development in engineering is high with a significant amount designated specifically for base isolation; the large construction companies aggressively market the technology; the approval process for constructing a base-isolated building is a straightforward and standardized process; and the high seismicity of Japan encourages the Japanese to favor the long-term benefits of life safety and building life-cycle costs when making seismic design decisions.

The system most commonly used in the past has been natural rubber bearings with mechanical dampers or lead-rubber bearings. Recently, however, there has been an increasing use of high-damping natural rubber isolators. There are now several large buildings that use these high-damping bearings: an outstanding example is the computer center for the Tohoku Electric Power Company in Sendai, Miyako Province.



Tohoku electric Power Company, Japan.

Photo: P.W. Clark

of the isolators is around 12 cm (4.8 in.). A fixed-base building adjacent to the computer center experienced some damage, but there was no damage to the isolated building.

Currently the largest base-isolated building in the world is the West Japan Postal Computer Center, located in Sanda, Kobe Prefecture. This six-story, 47,000 m square (500,000 ft square) structure is supported on 120 elastomeric isolators with a number of additional steel and lead dampers. The building, which has an isolated period of 3.9 sec, is located approximately 30 km (19 miles) from the epicenter of the 1995 Hyogoken Nanbu (Kobe) earthquake, and experienced severe ground motion. The peak ground acceleration under the isolators was 400 cm/sec square (0.41 g) but was reduced by the isolation system to 127 cm/sec square (0.13 g) at the sixth floor. The estimate of the displacement

The use of isolation in Japan continues to increase, especially in the aftermath of the Kobe earthquake. As a result of superior performance of the West Japan Postal Computer Center, there has been a rapid increase in the number of permits for base-isolated buildings, including many apartments and condominiums.

Summary

Ongoing research has improved the effectiveness of isolators in decreasing problems of stability, roll-out, failure of the isolators, or unexpected response and the trend away from add-on mechanical dampers. Additionally, the difficulties of manufacturing large isolators have diminished. It is now possible to make bearings as large as 60 in. (1.5 m) in diameter. The 70 natural rubber bearings built for the M.L. King/C.R. Diagnostics Trauma Center in Willowbrook, California, were at the time of their manufacture the largest isolation bearings in the U.S. The isolators are 1.0 m (40 in.) in diameter. The combination of increased size with low-modulus rubber has resulted in highly reliable isolation systems.

There are several local applications of seismic isolation systems. The Oakland City Hall was retrofitted after the 1989 Loma Prieta, California, earthquake with about 110 large isolators. A new public safety building for Berkeley is now under construction and will use seismic isolators. The Martin Luther King Jr. Civic Center Building in Berkeley will be retrofitted using isolation, as will the Hearst Memorial Mining Building on the University of California at Berkeley campus. The classic Beaux Arts architecture and interior fixtures will be untouched by the retrofitting process, while the seismic resistance will be substantially enhanced.

To date 45 base-isolated buildings in the U.S. are planned, under construction, or completed—for new construction and for retrofitting. The use of base isolation applications up to this time in the U.S. has been for structures with critical or expensive contents, but there is increasing interest in applying this technology to public housing, schools, and hospitals in developing countries, where the replacement cost due to earthquake damage can be a significant part of the gross national product. The cooperation between EERC and MRPRA led to a new joint effort supported by the United Nations Industrial Development Organization (UNIDO) that developed low-cost isolation systems for such countries, and several demonstration projects are in place in Indonesia, the People's Republic of China, and Armenia. The research program at EERC, initially supported by MRPRA, was instrumental in making the base isolation approach to earthquake-resistant design a reality.

This paper is an update of "Base Isolation: Origins and Development," EERC News, Vol. 12, No. 1, January 1991.,

REFERENCES

- Clark, Peter W., Masahiko Higashino, and James M. Kelly. 1996. "Performance of Seismically Isolated Structures in the January 17, 1994 Northridge Earthquake." *Proceedings of the Sixth U.S.-Japan Workshop on the Improvement of Building Structural Design and Construction Practices in the United States and Japan*. Victoria, B.C., Canada: Applied Technology Council and Japan Structural Consultants Association. ATC-15-5.
- Kelly, James. M. 1997. *Earthquake-Resistant Design with Rubber*. 2nd ed. Berlin and New York: Springer-Verlag.
- Taniwangsa, Wendy, and James M. Kelly. 1996. *Experimental and analytical studies of base isolation applications for low-cost housing*. Berkeley, Calif.: Earthquake Engineering Research Center, University of California. UCB/EERC-96/0